Outgoing Longwave Radiation Diurnal Variation from GOES Observations

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Introduction

We are developing a suite of algorithms similar to those developed for the High-resolution Infrared Sounder (HIRS) that will retrieve the longwave radiation budget variables using Advanced Baseline Imager (ABI) and Hyperspectral Environmental Suites (HES) radiance measurements onboard the GOES-R satellite. The planned products include the outgoing longwave radiation (OLR) at the top of the atmosphere, the atmospheric layer longwave cooling rate, and the downward longwave radiation at the Earth's surface, whereas the OLR is the primary product.

Past research at the CICS has adapted the multi-spectral OLR algorithm to GOES Sounder (Ba *et al.*, 2003) and Imager (Lee *et al.*, 2004) instruments. GOES Sounder OLR was validated against the Cloud and Earth's Radiant Energy System (CERES) broadband observations with expected accuracy. Both GOES Sounder and Imager OLR data have been used in the study of the OLR diurnal variations and demonstrated the need of sufficient temporal sampling for daily to monthly integral purposes. GOES-R OLR will have the advantages of accuracy as well the spatial coverage and temporal sampling that are expected to be better than with the GOES Sounder and Imager combined.

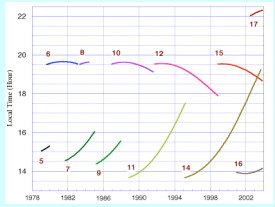
Here we compare the climatological all-sky monthly diurnal cycles derived with HIRS OLR data with the diurnal variations observed by the GOES Imager, as a demonstration of the GOES-R product. We discuss the implications regarding the representativeness of the empirically derived diurnal model and assess the errors in deriving the monthly/daily mean OLR using this diurnal model.

HIRS Diurnal Model

The lack of sufficient diurnal variation information in the HIRS OLR data is one of the sources of error when deriving the daily/pentad/monthly means. To minimize the impact of insufficient observations, we developed an empirical diurnal model similar to that of Gruber and Chen (1988). The empirical diurnal model was developed based on the 25 years of inter-satellite calibrated HIRS OLR retrievals averaged at the respective observation time in each 2.5°x2.5° area for each month. The diurnal model was formulated as a modified second order Fourier expansion as

$$OLR = a_0 + a_1 COS\frac{\pi(t-t_0)}{12} + a_2 COS\frac{2\pi(t-t_0)}{12}$$

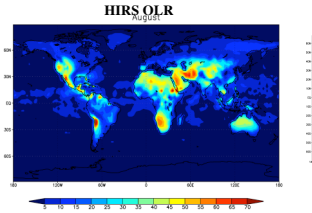
where t is the observation local time. The coefficients a_0, a_1, a_2 and the phase t_0 are determined from least square regression.



- This shows the overlap conditions of the TIROS-N series POES and the magnitudes of orbital drift (i.e., the change of equator crossing time).
- Out of the 297 months in the period from January 1979 to September 2003, about 76% of the months contain observations from two to four satellites. Whereas the months with observations from only one satellite were mostly before 1988.

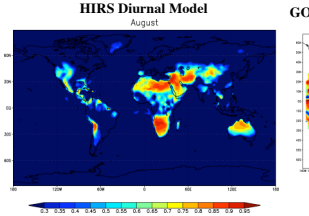
References:
Ba, M., R. G. Ellingson and A. Gruber, 2003: Validation of a technique for estimating OLR with the GOES sounder. J. Atmos. Ocean. Tech., **20**, 79-89.
Ellingson, R. G., D. J. Yanuk, H.-T. Lee and A. Gruber, 1989: A technique for estimating outgoing longwave radiation from HIRS radiance observations. *J. Atmos. Ocean. Tech.*, **6**, 706-711.
Gruber, A., and T. S. Chen, 1988: Diurnal variation of outgoing longwave radiation. *J. Climatol.*, **8**, 1-16.
Lee, H.-T., A. Heidinger, A. Gruber and R. G. Ellingson, 2004: The HIRS Outgoing Longwave Radiation product from hybrid polar and geosynchronous satellite observations. *Advances in Space Research*, **33**, 1120-1124.

GOES Diurnal Model

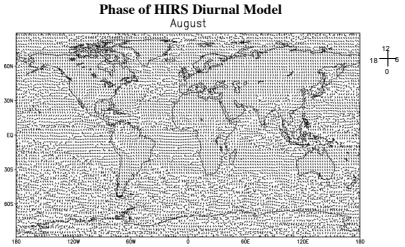


Range of the OLR diurnal variation of the climatological August HIRS OLR and the GOES Imager OLR in August 5-20, 2002. It can be seen that they have similar locations of strong OLR diurnal variations.

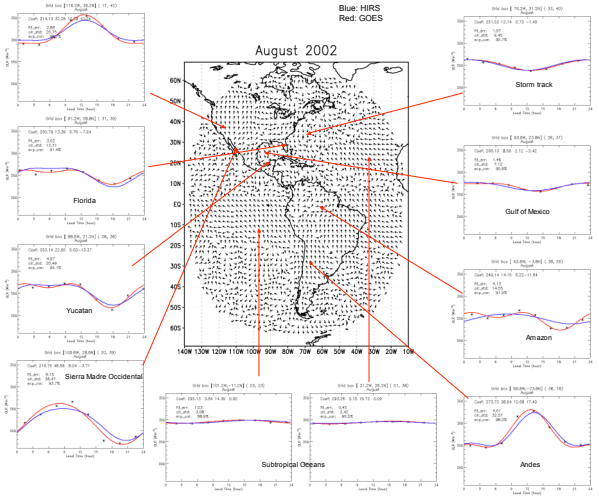
We used GOES OLR data to evaluate the HIRS diurnal models. For comparison purpose, the same diurnal model formulation is also used for GOES.



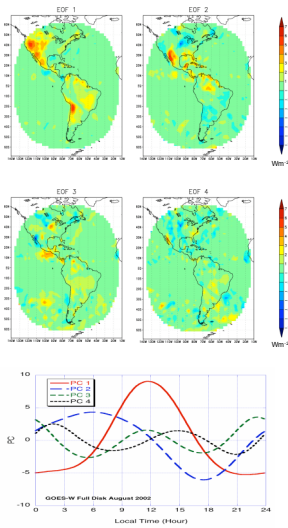
Explained variance of Diurnal Variation by the diurnal model. Over the oceans, the OLR interannual variations usually are in comparable magnitude with their diurnal variations. It is therefore difficult to derive accurate diurnal model using HIRS data. But for GOES OLR for the month of August, 2002, vary high degree of variance is explained by this diurnal model.



The phase term in the diurnal model is usually associated with the time of maximum OLR. But when the OLR diurnal variation presents complicated forms, e.g., typically two minima with one in the afternoon and one in the early morning, this phase term no longer indicates the maximum OLR hour.



EOF Analysis of GOES OLR Diurnal Variation



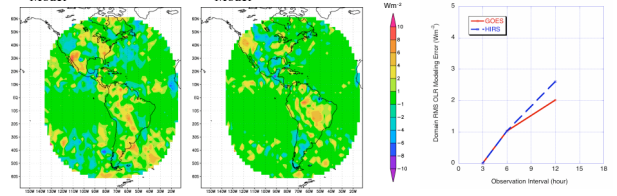
The first mode describes the OLR diurnal cycle in response to the solar heating of the Earth's surface without interference of cloud activities. This type of diurnal variation is usually seen in desert and mountain regions (e.g., Andes). The second mode describes daytime convectivity that peaks in the late afternoon hours. Regions with sufficient hot surface and source of water (e.g., coastal or heavily vegetated land) could have low OLR in the afternoon due to convective clouds (e.g., Sierra Madre Occidental). In some places there are two maximum convective activities during the course of a day (e.g., Amazon) that this kind of diurnal cycle could be explained by introducing the third and higher EOF models. The diurnal variation range for clear sky ocean is very small, typically around 5 Wm^{-2}, where the maximum occurs in the afternoon hour due to slower heating with water's larger heat capacity (e.g., Pacific Ocean in subtropical high zone). Oceans with cloud activities can still have relatively large diurnal variation (e.g., Gulf of Mexico) where the daytime cloud activities lead to a minimum OLR in the afternoon hours.

Error Assessment for Daily Mean OLR

Daily mean OLR error with 12-hourly obs. using **GOES** Diurnal Model

Daily mean OLR error with 12-hourly obs. using **HIRS** Diurnal Model

Domain average of Daily mean OLR error as a function of sampling interval with the diurnal model



Since the diurnal model was constructed with the GOES 3-hourly observations, we can assess the modeling error by reducing the number of observations, e.g., 6 or 12-hourly. The representativeness of HIRS diurnal model is assessed similarly using GOES 3-hourly integral as the reference. The increased daily mean error in HIRS daily mean is the indication of lack of representativeness of HIRS diurnal model derived with the composite data from different years. **The results suggested that the HIRS diurnal model is representative when observations are obtained 6 hourly or more frequently.** The daily mean error with 12-hourly observations using HIRS diurnal model is only slightly larger than that using GOES diurnal model. This suggests that most daily mean error might be originated from the diurnal modeling error. **The domain average of daily mean OLR are accurate to within 3 Wm^{-2} with two or more observations a day when diurnal model is employed .**

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